

## Battery Protection Circuit

### BACKGROUND

#### TECHNICAL FIELD

5 This invention relates generally to protection circuits for rechargeable battery packs, and more specifically to protection circuits that disable a rechargeable battery pack due to an excessive amount of current or power being supplied to the load.

#### BACKGROUND ART

Portable electronic devices, like cellular telephones, pagers and two-way radios 10 for example, derive their portability from rechargeable batteries. Such batteries allow these devices to slip the surly bonds of wall mounted power supplies and wirelessly touch the hand of the user wherever he may be.

While many people may think that a rechargeable battery is simply a cell and a plastic housing, nothing could be further from the truth. Rechargeable battery packs often 15 include circuit boards, electronic circuitry, mechanical assemblies and electromechanical protection components. The circuits employed in rechargeable battery packs include charging circuits that control current, fuel gauging circuits, temperature measurement circuits and indicator circuits, just to name a few. Simply put, a battery pack is a complex system of components working in harmony to safely deliver power to a portable 20 electronic device.

One of the most fundamental circuits in a battery pack is the protection circuit. Rechargeable battery performance, especially with respect to those having cells constructed of lithium-based materials, may be severely compromised if the cell within

the battery pack is over or under charged. For this reason, most all battery packs today include one form of safety circuit or another.

Typical safety circuits include voltage and current limits. As such, when the voltage across the cell in a battery pack becomes too high or too low, the safety circuit 5 will open switches within the pack, thereby “turning off” the battery pack. Similarly, if the current flowing either into or out of the cell gets too high, the safety circuit will turn off the battery pack.

Despite these voltage and current safety mechanisms, new concerns are arising from “thermal” situations. These situations arise when a battery pack is operating within 10 its voltage and current limits, but the internal temperature – which is proportional to the power being dissipated within the device – becomes too high for a particular application. The concern is that the thermal situation may cause components within the electronic device to become so hot that reliability of the overall system may become compromised.

There is thus a need for an improved battery safety circuit that turns off the battery 15 not only due to excessive voltage or current, but for excessive heat as well.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 illustrates a block diagram of a safety circuit IC.

FIG. 2 illustrates a protection circuit having a safety circuit and charge monitoring circuit 20 in accordance with the invention.

FIG. 3 illustrates one embodiment of a power monitoring circuit in accordance with the invention.

FIG. 4 illustrates one preferred embodiment of a pulsed current detector in accordance with the invention.

FIG. 5 illustrates a protection circuit having a plurality of safety circuits and charge monitoring circuits in accordance with the invention.

5 FIG. 6 illustrated one preferred embodiment of coupling a power monitoring circuit and a pulsed current detector together in accordance with the invention.

### **DETAILED DESCRIPTION OF THE INVENTION**

A preferred embodiment of the invention is now described in detail. Referring to 10 the drawings, like numbers indicate like parts throughout the views. As used in the description herein and throughout the claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise: the meaning of “a,” “an,” and “the” includes plural reference, the meaning of “in” includes “in” and “on.”

Copending, commonly assigned application No. 10/737,021, entitled “Power 15 Fault Battery Protection Circuit”, filed December 16, 2003, which is included herein by reference, teaches a circuit that simulates an overcurrent condition in a battery safety circuit when power being delivered to or from a rechargeable cell exceeds a predetermined threshold, like 9 watts for example. This circuit prevents current flow to or from the battery when this threshold is exceeded, with the goal of preventing the overall 20 battery pack from overheating.

While this circuit works well in practice, situations can arise where the circuit gets hot despite the fact that the average power is below a threshold of 9 watts. Such a

situation occurs when the power is “pulsed” from the cells, rather than being continuously drawn from the cells.

The power detection of the ‘021 application is performed by an analog multiplier circuit that measures average voltages and currents. Many electronic circuits today, 5 however, used pulsed power during operation. In other words, rather than drawing a nice, steady stream of power, they draw power in short packets or bursts. Unless the components of the power measurement circuit are expensive, high precision parts, the power detector may miss these pulsed packets of energy, measuring instead an average energy that does not cause the overcurrent condition to be simulated.

10 This invention rectifies this situation by providing a pulsed current detector that measures and integrates pulses. In one preferred embodiment, the pulsed current detector is coupled along side the power monitoring circuit so that either an average power above a predetermined threshold, or a plurality of pulses across time above a predetermined threshold, will simulate an overcurrent condition in the safety circuit. In the pulsed current detector, when a sufficient number of pulses have been drawn within a certain 15 amount of time, i.e. an amount of pulses that constitutes an amount of coulombs exceeding a predetermined threshold, the pulse detector actuates, thereby causing an overcurrent situation to be simulated in the safety circuit.

As such, this invention provides a charge monitoring circuit, comprising a power 20 monitoring circuit and a pulsed current detector, that may be used in conjunction with an existing battery safety circuit to offer protection against overheating. The charge monitoring circuit monitors not only average power, but also the integral of current being delivered to or from the cells in a battery pack. When either the power or integrated

current exceeds a predetermined threshold, the charge monitoring circuit simulates an overcurrent condition in the safety circuit. This overcurrent simulation causes the safety circuit to open one or more serial pass elements, for example transistors, thereby isolating the cells from the external terminals of the battery pack. The charge monitoring circuit is 5 then capable of resetting itself when the load is removed from the battery pack. The combination of the charge monitoring circuit with the conventional battery safety circuit provides a system that protects not only from excessive voltages and currents, but from excessive thermal levels as well.

Prior to understanding the power monitoring circuit, a brief overview of battery 10 safety circuits is warranted. As used herein, a “safety circuit” is any circuit capable of monitoring the voltage across at least one rechargeable cell, in addition to being capable of monitoring the current flowing through the cell or cells. One example of such a circuit is the S8232 series of safety circuits manufactured by Seiko Instruments, Inc. For discussion and exemplary purposes, such a circuit will be discussed herein. It will be 15 clear to those of ordinary skill in the art who have the benefit of this disclosure, however, that the invention is not so limited. Discrete circuits, application specific circuits and safety circuits manufactured by other companies, including Ricoh and Mitsumi for example, may be equally substituted for the Seiko circuit.

By way of background, referring now to FIG. 1, illustrated therein is a block 20 diagram of an S-8232 safety circuit 100. The S-8232 safety circuit is designed to be used with two, serial, lithium-based cells. Again, it will be clear to those of ordinary skill in the art with the benefit of this disclosure that the invention is not so limited. The overpower

circuit discussed herein may be equally applied to any combination of serial or parallel cells.

The safety circuit 100 may be as simple as a single integrated circuit (IC) that provides a means for monitoring of cell voltage and current, and thereby controls the 5 charging and discharging of the cells within a battery pack. Discrete equivalents of the IC may also be substituted. The safety circuit 100 includes an overcharge detector 101 that monitors the voltages across the corresponding cells. The overcharge detector 101 compares these voltages to a predetermined maximum cell voltage. When the cell voltage exceeds this threshold, the overcharge detector 101, via some internal logic circuitry 103, 10 causes a push-pull output stage 114 to actuate the charge pin 107. When the charge pin 107 is coupled to a disconnect means, like a transistor acting as a switch in its non-linear region, actuation will prevent any further charging of the cells.

Similarly, the safety circuit includes an overdischarge detector 102 that ensures that the voltage across the cells does not fall below a predetermined threshold. If it does, 15 the overdischarge detector 102 causes an output stage 113 to actuate the discharge pin 106. When the discharge pin 106 is coupled to a disconnect means, like a serial transistor, actuation prevents any further discharge of the cells.

Cell current is monitored by way of an overcurrent detection pin 108 coupled to an overcurrent detection circuit 104. The overcurrent detection pin 108 senses the voltage 20 between the Vss pin 112 and the overcurrent detection pin 108. When this voltage exceeds a predetermined threshold, as will be explained in more detail later, the overcurrent circuit 104 causes the discharging pin 106 to actuate, thereby stopping the

flow of current in the discharge direction. In some situations, with some safety circuits, the charging pin 107 may also actuate.

When the load is removed, as evidenced by an impedance greater than  $200\text{ M}\Omega$  appearing between the Sens pin 110 and the overcurrent pin 108, the safety circuit 100 5 resets, thereby deactuating the discharge pin 106. This action will be more evident with the discussion of FIG. 2 below.

Other components of the safety circuit 100 include a Vcc pin 109, a center tap pin 111, and a Vss pin 112, that monitor the voltage at the cathode, between, and at the anode of serial cells, respectively. Additionally, a delay circuit 105 provides some hysteresis and 10 transient immunity.

Referring now to FIG. 2, illustrated therein is one preferred embodiment of a battery protection circuit in accordance with the invention. The safety circuit 100 from FIG. 1 is coupled to a pair of rechargeable cells 201,202. The charge pin 107 and the discharge pin 106 are coupled to disconnect elements 203,204, respectively, which are in 15 turn coupled serially with the cells 201,202. The disconnect elements 203,204 in this exemplary embodiment are field effect transistors (FETs), although other devices, including switches, relays, circuit breakers, positive temperature coefficient devices and controllable fuses may be substituted, depending upon the application.

The overcurrent pin 108 is coupled to the low side 205 of the circuit, such that the 20 overcurrent pin 108 may work in conjunction with the Vss pin 112 to sense the voltage across the FETs 203,204. When this voltage becomes too high, the safety circuit 100 knows that the current being drawn from the cells 201,202 is correspondingly too high. When this occurs, the discharge pin 106 causes FET 203 to open, thereby preventing

current from flowing to the external terminals 206,207. The safety circuit 100 resets, and thus closes FET 203, when an impedance greater than  $200\text{ M}\Omega$  is sensed between the Sens pin 110 and the overcurrent pin 108. This happens when a load (not shown) is removed from the terminals 206,207, thereby creating essentially an open circuit between 5 the terminals 206,207.

The charge monitoring circuit 220 includes circuitry for monitoring rechargeable cell parameters, including power, voltage, current and energy. In one embodiment, this circuitry includes a power monitoring circuit 208 and a pulsed current detector 221. The power monitoring circuit 208 includes a power meter 209 that acts as a means of 10 monitoring power being delivered to or from the cells 201,202. The power meter 209, explained in more detail with the discussion of FIG. 3, can comprise any circuit that is capable of determining whether the product of the voltage across the at least one rechargeable cell and the current flowing through the at least one rechargeable cell exceeds a predetermined threshold. It may include a circuit that generates a signal that is 15 proportional to the product of the voltage across the cells and the current flowing through the cells. It may also be a circuit that simply generates a binary, up or down signal that indicates whether the power is above or below the threshold. The power meter 209 may be an accurate, linear power meter, or may be a simpler circuit that approximates power, for example by way of piecewise linear or other approximation means.

20 The power signal 210 is then coupled to a comparator 211 that has a signal 212 (like a reference voltage, for example) that is proportional to the predetermined threshold of power. When the power signal 210 exceeds the predetermined threshold 212, the comparator 211 actuates. The predetermined threshold may be set to any level required by

the application. One exemplary threshold for a two-serial-cell configuration, that is intended to comply with a corresponding temperature threshold limit set forth by the Atmospheric Explosive (ATEX) directive set forth by the European Union, is nine watts. In any event, when the signal proportional to power is below the predetermined threshold, 5 the output 216 of the comparator 211 is in a first state. The output 216 of the comparator 211 switches to a second state when the signal proportional to power exceeds the predetermined threshold.

When the power sourced from the cells 201,202 exceeds the predetermined threshold, the power monitoring, or “overpower”, circuit 208 simulates an overcurrent 10 condition within the safety circuit 100, causing FET 203 to open, or enter a high impedance state thereby preventing current from flowing from the cells 201,202. The overcurrent condition is simulated by sourcing current into the overcurrent pin 108 (as a result of increased voltage at the overcurrent pin 108), and thus into the overcurrent detection circuit within the safety circuit 100.

15 Such an overpower condition might arise as follows: The power meter 209 would be continually monitoring the power sourced from the cells 201,202. The load connected to the terminals 206,207 would begin drawing power in excess of the predetermined threshold. The power meter 209 determines that this is the case, causing the power signal 210 to rise above the power threshold signal 212. This, in turn, actuates the comparator 20 211.

A switch 219, shown here as a FET, is responsive to the comparator and closes upon actuation of the comparator 211. This pulls the overcurrent pin 108 to the cell voltages, thereby causing current to flow into the overcurrent pin 108 through a current

limiting resistor 213. To the safety circuit 100, this appears to be an actual overcurrent situation in the battery pack. The safety circuit 100 then opens the discharge FET 203, thereby preventing any current from flowing out of the cells 201,202. As such, the cells 201,202 are effectively disconnected from the terminals 206,207 as a result of power 5 dissipation exceeding the predetermined threshold. An optional delay circuit 218, perhaps a resistor-capacitor filter for example, may be coupled between the comparator 211 and the switch 219 where a delay prior to opening the FET 203 is desired. Such a delay may be desirable when a host device needs time to complete an operation prior to power down.

10 In parallel, an optional second disconnect means 214, shown here as a FET, may be coupled to the comparator 211 so as to be responsive to the comparator 211. The second disconnect means 214, coupled serially between the terminals 206,207 and the cells 201,202, operates as a secondary circuit breaker and opens when the comparator 211 is actuated. As such, if the discharge FET 203 fails, the second disconnect means will still 15 disconnect the cells 201,202 from the terminals 206,207 when an overpower condition occurs.

20 Note that this second disconnect means 214 is optional, as it is advantageous in some designs. For example, in circuits where redundancy is needed for reliability, a designer may decide to employ two separate safety circuits, using the second safety circuit to control a second discharge FET, which would thus serve as the optional second disconnect means. In such a case, one example of which is illustrated in FIG. 5, either the power monitoring circuit 208, or a redundant power monitoring circuit 501, would be connected to the overcurrent pin 502 of a second safety circuit 503, with the charge and

discharge FETs 504,505 of the second safety circuit 503 being coupled serially with the terminals 206,207, the cells 201,202, and the first charge and discharge FETs 203,204. Other designs may need neither the second safety circuit nor the second disconnect means.

5 When a second disconnect means 214 is used, a leakage current path in parallel with the second disconnect means 214 is provided by a resistor 215. The resistor 215 provides a latching mechanism that causes the safety circuit 100 to remain in the simulated overcurrent condition. Recall that the safety circuit 100 resets when the impedance between the sense pin 110 and the overcurrent pin 108 exceeds 200 MΩ. This  
10 would be the case when the second disconnect means 214 opens. As such, a leakage path provided by the resistor 215 ensures that the safety circuit 100 stays latched in the simulated overcurrent condition until the load is removed from the terminals 206,207. Resistance values for resistor 215 range from 100kΩ to 500kΩ, preferably about 200kΩ.  
Note that when a second safety circuit is used to control the second disconnect means  
15 214, the leakage current path may not be necessary, as the second safety circuit provides an internal leakage path.

As stated, when the overpower, and thus the simulated overcurrent, condition is initiated, the cells 201,202 are disconnected from the terminals 206,207 by way of FET 203. In such a state, it is not desirable to have electrical components within the battery  
20 pack discharge the cells 201,202. As such, the invention provides a means of disabling the power monitoring circuit 208. Disablement is accomplished by a switch coupled between the high side terminal 206 of the circuit and the power monitoring circuit 208.

This switch 217, shown for exemplary purposes as a FET, is coupled to the discharge pin 106 of the safety circuit 100.

When the discharge pin 106 is actuated, the switch 217 turns off, thereby blocking current from flowing to the overpower circuit. Thus, in an overpower condition, the 5 power monitoring circuit 208 first simulates an overcurrent condition in the safety circuit 100, thereby causing the discharge pin 106 to actuate. This, in turn, causes the switch 217 to open, thereby deactivating the power monitoring circuit 208.

Such a scenario is perfectly acceptable, in that the power monitoring circuit 208 is no longer needed to monitor power being delivered from the cells 201,202, as there is no 10 power being delivered from the cells 201,202 since the charge and discharge FET 203 is open. Upon removal of the load, however, the safety circuit 100 resets, thereby causing closure of the FET 203, thereby closing the switch 217, thereby reactivating the power monitoring circuit 208. The safety circuit will then revert back to normal operation.

A pulsed current detector 221 provides a solution to the situation mentioned 15 above when average power is below the critical threshold, yet a load is drawing pulsed current at a rate high enough to cause internal battery components to get hot. The pulsed current detector 221 is functionally “OR’ed” with the power monitoring circuit 208 such that when either the power monitoring circuit 208 or the pulsed current detector 221 trips, an overcurrent condition is simulated within the safety circuit 100. Note that the pulsed 20 current detector 221 may be used without the power monitoring circuit 208 as well.

The pulsed current detector 221 includes a current integrator 222. The current integrator 222 integrates pulses of current based upon a voltage generated by the current sense resistor 223. The current sense resistor 223 is a low-impedance resistor, on the

order of a few ohms or less. When current flows through the current sense resistor 223, a corresponding voltage proportional to the current level is generated. This voltage is integrated across time by the current integrator 222, which includes a decay so as to keep a running sum of current pulses across a predetermined amount of time.

5        When the sum of current pulses, corresponding to an amount of charge in coulombs delivered from the cells, exceeds a predetermined current threshold an overcurrent situation is simulated within the safety circuit 100. The way that this occurs is as follows: an output 224 of the current integrator 222 is coupled to a first input of a comparator 225. A second input is coupled to a voltage 226 that corresponds to the 10      predetermined threshold of integrated current.

So long as the sum of current pulses across a predetermined time stays below the predetermined threshold, and thus below the reference voltage 226, the comparator remains in a first, low state. However, when the sum of current pulses across a predetermined time, as determined by the current integrator 222, exceeds the reference 15      voltage 226, comparator 225 moves from a first state to a second, high state, thereby actuating transistor 219. The actuation of transistor 219 sources current into the overcurrent detection pin 108, thereby simulating an overcurrent condition as mentioned above.

Referring now to FIG. 3 illustrated therein is one example of a power meter 209 in 20      accordance with the invention. The power meter 209 includes a means for measuring or sensing the voltage across the cells, as well as a means for measuring or sensing the current flowing through the cells. Both the means of measuring voltage and current may comprise analog amplifiers 301,302 coupled to the cells. In the case of voltage, the

amplifier 301 may have inputs coupled across the cells to measure the voltage. The gain of the amplifier 301 would be scaled such that the product output is at a level that is acceptable by the comparator.

In the case of current, the amplifier 302 input may be coupled to a means of 5 sensing current, like a current sense resistor for example. As with the voltage amplifier 301, the gain of the current amplifier 302 would be scaled such that the product output is at a level that is acceptable by the comparator.

The outputs of the amplifiers 301,302 are then fed into an analog multiplier 303. 10 The analog multiplier produces a product output 304 that is proportional to the product of voltage and current. This output 304 is then fed to the comparator 211. One example of an analog multiplier is taught in US Pat. No. 3,562,553, entitled "Multiplier Circuit, issued to Roth, which is incorporated herein by reference.

Note that the power meter of FIG. 2 and the multiplier circuit of FIG. 3 are but 15 one exemplary embodiment of a power meter in accordance with the invention. It will be clear to those of ordinary skill in the art who have the benefit of this disclosure that the invention is not so limited. Numerous other power measurement circuits, including those employing logarithmic amplifiers, microprocessors with analog to digital converters, hall effect multipliers, and other analog and digital circuits may be equally substituted. The only requirement is that the power measurement circuit be capable of producing a signal 20 proportional to the amount of power being sourced from, or delivered to, the cells.

Referring now to FIG. 4, illustrated therein is one preferred embodiment of a pulsed current detector 221 in accordance with the invention. As mentioned with the discussion of FIG. 2, the pulsed current detector 221 includes a current integrator 222 and

a comparator 225 having at least a pair of inputs 403, 404. A voltage proportional to the current flowing to or from the rechargeable cells is coupled to the first input 403, while the reference voltage corresponding to the predetermined current threshold is coupled to the second input 404. An integrating capacitor 400 is coupled to the first input 403 for the 5 purpose of integrating the current pulses.

When current flows through the current sense resistor 223, a voltage corresponding to the current is applied to an amplifier 401. As the current sense resistor has a low impedance value, the amplifier 401 will generally provide gain to magnify the signal. When pulsed, i.e. changing, current is to be sensed, a capacitor 402 is included in 10 the feedback loop to block DC signals from becoming amplified.

The output of the amplifier 401 is then coupled to the integrating capacitor 400. This capacitor 400 provides the summing function that integrates the pulses of current. As there is decay associated with the voltage of the capacitor due to the finite input impedance of the comparator 225, the capacitor 400 effectively sums pulses for a finite, 15 predetermined amount of time. When the voltage across the capacitor 400 increases above the reference voltage 226, the comparator 225 switches from a first state to a second state. In one preferred embodiment, conforming with the ATEX standard mentioned above, a 1uF capacitor is used with a 1.2 V reference. As such when pulsed current exceeds 1.2 uCoulombs prior to decay, the comparator 225 will switch.

20 Turning briefly to FIG. 6, illustrated therein is one preferred embodiment of OR'ing the pulsed current detector 221 and the power meter 209. The OR function is performed by a pair of transistors 600,601. In this exemplary embodiment, transistor 601

is a p-channel device, while transistor 600 is a n-channel device. The power meter 209 turns on transistor 601 simply by toggling the control line from high to low.

The pulsed current detector 221 is coupled to transistor 601 via transistor 600. When the output 603 of the pulsed current detector transitions from low to high, transistor 5 600 turns on, thereby actuating transistor 601. The turning on of transistor 600 is independent and does not affect the power meter 209.

When either the power meter 209 or pulsed current detector 221 actuate transistor 601, the signal then passes through the optional delay circuit 218 to transistor 219. The actuation of transistor 219, which is coupled to the safety circuit 100, causes the 10 overcurrent condition to be simulated.

Referring now to FIG. 5, illustrated therein is a battery circuit having redundant safety circuits 100,503. The first safety circuit 100 is coupled to a charge 203 and discharge 204 transistor, while the second safety circuit 503 is coupled to a second charge 504 and discharge 505 transistor. The duplicity of safety circuits 100,503 offers added 15 reliability, in that if either one or the other of the safety circuits fails, the remaining one will offer charge protection.

Corresponding with the plurality of safety circuits is a first 220 and second 506 charge monitoring circuits. Each charge monitoring circuit 220,506 is coupled to a corresponding overcurrent monitoring pin 108,502. Each charge monitoring circuit 20 220,506 comprises a power meter 209,507 and a pulsed current detector 221,508, coupled in the OR configuration of FIG. 6.

When either of the power meters 208,507 senses that power has exceeded a predetermined threshold, or when either of the pulsed current detectors 221,508 senses

that the integrated current exceeds a predetermined threshold, an overcurrent condition will be simulated in the corresponding safety circuits 100,503 by way of transistors 219,509. It will be obvious to those of ordinary skill in the art who have the benefit of the disclosure that other detectors, in addition to or as substitutes for the power and current 5 detectors, including temperature detectors, pressure detectors, energy detectors voltage detectors and the like may be used as well. The circuit of FIG. 5 offers a highly reliable battery circuit that ensures that components within the battery will not become overheated during operation.

While the preferred embodiments of the invention have been illustrated and 10 described, it is clear that the invention is not so limited. Numerous modifications, changes, variations, substitutions, and equivalents will occur to those skilled in the art without departing from the spirit and scope of the present invention as defined by the following claims. For example, while one preferred embodiment of the invention is a rechargeable battery pack comprising the battery protection circuit taught in FIG. 2, the 15 invention is not so limited. It may be applied to any power source, including power supplies, fuel cells, solar cells and the like. Additionally, it may be incorporated into the host device as well as within the battery pack.